ARIZONA STATE PARKS
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BACKGROUND INFORMATION
KARTCHNER CAVERNS STATE PARK

Assessment of hydrological impacts on Kartchner Caverns State Park of a proposed Whestone Springs Resort

By Tom Aley, Director and President of the Ozark Underground Laboratory (see biography at end of this report)

Assessment Comments

1. At first blush it would seem that a major resort development on the north edge of Kartchner Caverns State Park would not be likely to impact adjacent park lands or the nationally famous Kartchner Caverns. After all, the nearest presently known cave passages are about 2,950 feet from the edge of the proposed development, and most of the cave and most of the proposed developments are separated by even greater distances. However, that "first blush perception" is wrong, and I am pleased that Arizona State Parks has retained me to assess the issues and has made it possible for me to meet with all of you today.

2. Four years ago the editors of Encyclopaedia Britannica asked me to review the man-made threats endangering many of the world's caves and to prepare a feature article for the 1997 annual Science and the Future volume. The title they chose was "Caves in Crisis"; it was appropriate.

3. As with the issues here at Kartchner Caverns, too many "first blush" perceptions about the linkages between land use and valuable caves have been very wrong. In the Encyclopaedia Britannica article I said that: Caves contain remarkable treasures, but they are treasures that are, unfortunately, accompanied by four unique "curses". The first curse is that the treasures lose their value if they are removed from the cave. The second is that many cave treasures are extremely fragile. The third is that changes to the cave microclimate can also damage or destroy valuable treasures. The fourth is that caves are intimately connected with the land in which they are located and with the lands which supply them with water. The present issues here at Kartchner Caverns threaten the cave via three of the four "curses". We are dealing with fragility, the cave microclimate, and the intimate connection between caves and the lands in which they are located and the lands which supply them with water. Let me explain how and why.

4. Kartchner Caverns is a beautiful, delicate, and moist cave located in a block of heavily faulted, fractured, and tilted limestone which outcrops over much of Kartchner Caverns State Park.

5. Three brief definitions will be useful. Karst is a three-dimensional landscape developed on and in a soluble bedrock in which there is appreciable groundwater movement through dissolved out openings in the bedrock. An aquifer is a geologic unit or combination of units which can supply enough water to be of use. The recharge area for a cave is the land area which contributes water to the cave.

6. Water is critical to the beauty of the cave, its vitality, and thus to its protection. The air in the cave is constantly at or near 100% relative humidity. Such continuous high humidity in a cave surrounded by desert is highly unusual.

7. Based upon pre-development studies which I designed and directed, the evaporation loss of water from within Kartchner Caverns was 166,650 gallons per year (*Aley and Aley, 1990).* This was under pre-development conditions; present rates are undoubtedly greater, and this is presently an issue of concern. Drippage water entering the cave from overlying lands averages 62,000 gallons per year (*Graf, 1999*); this equals only 37% of the annual pre-development evaporation rates. The remaining 63% of the water available for evaporation is supplied by the Kartchner Aquifer. Under present conditions with greater evaporation the percentage of evaporation offset by drippage water from lands overlying the cave is even smaller.

8. The Kartchner Aquifer is a composite karst and fractured rock aquifer developed in the Kartchner Block of limestone and adjacent fractured rocks. Drewes (1980) mapped the block as comprising about 1200 acres. The Kartchner Aquifer essentially underlies the same area as the delineated Kartchner Block, and is thus about 1200 acres.

9. Storm events which occur on average about once every two years raise water to levels that create pools in cave passages. The volume of pooled groundwater in the cave on top of the cave floor has sometimes been as great as a million gallons. Additional water is retained in sediments, fractures, and voids beneath the floor level of the cave. The periodic rises in water levels in the aquifer, including (but not limited to) inundations, re-supply the mud on the cave floor with water.

10. In Kartchner Caverns, the expansive mud floors are at or near the normal top of the saturated portion of the Kartchner Aquifer. It is these mud floors, which are part of the aquifer, that supply much of the water which maintains the high relative humidity in the cave and off-sets the large volume of annual evaporation from cave surfaces. Even if water is not visible on top of the mud cave floors, moisture moves upward through the sediments due to capillary forces and maintains the high humidity in the cave.

11. The fundamental fact is this: The maintenance of the natural conditions and internationally recognized beauty of Kartchner Caverns depends upon maintenance of an adequate water supply (both in quantity and quality) in the Kartchner Aquifer. Years ago, coal miners took canaries into the coal mines; if the canary sickened, it was time to leave the mine. The water supply in Kartchner Caverns is the canary for this magnificent cave.

12. The following six items are some of the things that we know or can infer about the nature and functioning of the Kartchner Aquifer.

13. First, the aquifer is developed in faults, fractures, and dissolved out openings in the bedrock. Much of the aquifer contains fills which range from fine textured materials to gravel and large rocks plus a multitude of fractures and voids. As is obvious in the cave where passages have been formed along fault zones, preferential flow routes exist along faults and fracture zones. Limestones in fault contact with essentially insoluble rocks are especially susceptible to solution and development as major preferential groundwater flow routes.

14. Second, the thickness of the aquifer is unknown. Within Kartchner Caverns it is likely that major dissolved out openings in the aquifer extend tens of feet to perhaps 100 feet or more below typical floor elevations of the cave.

15. Third, all of the Kartchner Block has been subjected to essentially the same hydrogeological conditions which have resulted in the formation of Kartchner Caverns and the development of the Kartchner Aquifer. The limit of the aquifer is not the humanly accessible portions of Kartchner Caverns. Instead, Kartchner Caverns should be viewed as a “window” into the Kartchner Aquifer.

16. Fourth, groundwater tracing with fluorescent dyes has shown that both Saddle Wash and Guindani Wash contribute waters to the Kartchner Aquifer. It is my conclusion that Center Wash (located north of known portions of the Caverns), North Wash (which flows from some of the area proposed for development onto Kartchner Caverns State Park), and Ricketts Wash (located north of North Wash) also contribute water to the Kartchner Aquifer. No quantitative studies have been done to assess the relative importance of the various surface watercourses in recharging the Kartchner Aquifer.

17. Fifth, I am particularly concerned by the likelihood of preferential groundwater flow into Kartchner Caverns along the Saddle Wash Fault System. I have assigned the name “Saddle Wash Fault System” to the major fault or system of connecting faults which run northward along Saddle Wash within the park (and include the bounding fault for the Kartchner Block). About 300 feet south of the north boundary of the park the Saddle Wash Fault System curves toward the northeast and crosses North Wash and the major wash north of North Wash on the proposed resort development. The difference in elevation between the channels of these washes at the fault intersections and the floor of Kartchner Caverns is about 70 to 80 feet and the distances are a mile or less; the gradient is from the proposed development toward the Caverns. Groundwater gradients in karst aquifers similar to the Kartchner Aquifer are often only a foot or two per thousand feet; the gradient from the development to the Caverns is more than adequate to yield flow to the Caverns. In summary, much of the proposed resort development area contributes groundwater recharge to the Kartchner Aquifer, and the presence of the Saddle Wash Fault System provides a likely preferential flow route for water from the proposed development area to move to Kartchner Caverns. Documentation is as follows. In the proposed resort area the fault system is depicted on maps by Creasey (1967). In the park area it is shown on maps by Thomson (1990) and Graf (1999). Fluorescein dye was placed in Saddle Wash near this fault and was subsequently recovered in Kartchner Caverns (Aley and Aley, 1990).

18. Sixth, groundwater recharge through limestone units often flows more or less laterally along bedding planes and then lifts or sinks to other bedding planes along fracture zones and faults. The general dip of limestones in the Kartchner Block is toward the west and southwest. It is reasonable for waters sinking in the proposed development area and along the washes downstream of the developments to flow toward the west and southwest and thus into Kartchner Caverns State Park and into portions of Kartchner Caverns.

19. From the perspective of the underground resources in the Park, compatible land uses on the Kartchner Block are those which do not alter the quantity or quality of the water entering the Kartchner Aquifer. The following four points are examples of land use activities which would not meet this compatibility criteria.

20. First, activities which extract or divert water from the Kartchner Aquifer or decrease the location or quantity of recharge to the aquifer. Minor increases in recharge to the aquifer would be acceptable if that water is of near-natural quality.

21. Second, activities which introduce stormwater runoff which is not of near-natural quality. This could include increased sediment loads due to erosion of disturbed soils.

Among other impacts, such sediment can reduce groundwater recharge rates from water courses into the karst aquifer.

22. Third, stormwater runoff from roofs, roads, other paved surfaces, and from ornamental mulched plantings poses significant threats to aquifers associated with caves. As an illustration, my firm has a present project for a confidential client where stormwater runoff from a tourism development has introduced sufficient unnatural loads of organic matter into a nearby show cave that it has decreased oxygen concentrations and increased carbon dioxide concentrations in the cave. The extent of the changes in air quality have been so great as to require forced ventilation of the cave and periodic closure of the cave to tours during summer conditions. The movement of elevated carbon dioxide concentrations in the cave system can be rapid and for appreciable lateral distances. The cave temperatures at Kartchner Caverns are about 12 degrees F. higher than those at the problem site; elevated temperatures increase the rate of carbon dioxide generation resulting from biological decomposition of organic matter. The ventilation strategy used at this other cave would be disastrous at Kartchner Caverns.

23. Fourth, sewage from leaks and spills. Sewer systems serving developments and cities are routinely plagued by infiltration and exfiltration. The problems of sewer line exfiltration are particularly severe in karst areas because most of the leaks enter the groundwater system and provide no surface evidence of a leak. The magnitude of the problem was brought home to me about 15 years ago when I reviewed data on the amount of sewage reaching the sewer plant serving Mammoth Cave National Park, Kentucky. The volume of sewage reaching the plant in the summer (when tourism is greatest) was much less than it was in the winter (when there is little tourism). This was because most of the sewage from the park leaked out of the sewers and into dry soils and the karst aquifer in the summer, but in the winter water from the soils flowed into the sewer line. This system served only Mammoth Cave National Park, and was designed, installed, and maintained by professional engineers. The fundamental problem here is the nature of karst. Never assume that sewers won’t (or don’t) leak in karst landscapes. Because of the inherent problems with sewer line leaks in karst areas and their impacts on Hidden River Cave, the Caveland Sanitation Authority in Kentucky conveys all of its treated sewage through high density polyethylene pipe which has a great ability to stretch prior to rupture. This Authority took this and other steps to reduce sewer line leakage to the aquifer associated with Hidden River Cave and to rapidly find leaks when they occur. At Springfield, Missouri a break in a seven year old sewer line depleted oxygen in a karst aquifer and created strong, obnoxious odors at points up to 10,000 feet from the leak site.

24. McGraw Spring is the only perennial spring in the Kartchner Block. It discharges from a fault zone; this clearly demonstrates the hydrologic importance of faults in the area as preferential groundwater flow routes.

25. I examined North Wash on August 20, 2001. Debris levels in the channel of North Wash upstream of the Saddle Wash Fault System indicated flow rates of about 500 gallons per minute. Within about 150 feet of the intersection of the fault system and the channel of the wash there was no longer evidence of any flow in the wash from the recent storm. These observations demonstrate that, under storm runoff conditions, North Wash recharges the Saddle Wash Fault System at rates of 500 gallons per minute or more.

26. Ricketts Wash was also examined on August 20, 2001. As was the case with North Wash, this wash also crosses limestone units. Based upon debris marks, recent surface

flows also occurred in this wash and it appeared that at least some surface water from this wash also recharges the Saddle Wash Fault System.

Conclusions

The data which I have reviewed and summarized clearly demonstrate that it is more likely than not that the proposed rezoning and subsequent construction and operation of the envisaged resort will adversely impact the Kartchner Aquifer and resources including Kartchner Caverns which are dependent upon this aquifer.

Allen, Stephenson and Associates (ASA) (2001) prepared a brief preliminary analysis of the potential for the proposed development to impact Kartchner Caverns. Their report was presented to the Planning and Zoning Committee for the City of Benson. Aside from wishful thinking, there are no credible hydrologic or geologic data presented to indicate that the proposed development would not degrade Kartchner Caverns and other features in the park.

The ASA report was significantly deficient in not recognizing or discussing the potential hydrological significance of the Saddle Wash Fault System. Recognition and focused investigations of such features is a fundamental component of recharge area delineations and assessments in karst aquifers.

The existence of the Saddle Wash Fault System, a positive groundwater trace into the cave from a location near the fault system, other faults which trend southwestward or southward, the general southwestward dip of the bedrock, a more than adequate groundwater gradient, and field observations of August 20, 2001 provide strong evidence of a system of features very likely to transport groundwater from the proposed resort area into the park and, more likely than not, into Kartchner Caverns itself.

In addition, several concepts put forth by ASA (2001) warrant specific comments.

- ASA states that the proposed resort is separated from Kartchner Caverns by two distinct ridgelines and that this and other factors would provide a significant physical and visual buffer zone between activities on the resort and the Caverns. Groundwater flow moves down the slope of the water table. Groundwater cannot look up and see if it is passing tens or hundreds of feet beneath a distinct ridgeline. Many major caves have recharge areas shown by groundwater tracing studies to comprise many square miles of land; flow routes commonly pass beneath major ridges and even surface streams. As an illustration, fifty-nine groundwater traces have been conducted in delineating the recharge area for Tumbling Creek Cave at the Ozark Underground Laboratory in Missouri. The recharge area for this cave is over 9 square miles, and 90% of the recharge area for the cave is in surface basins other than the one in which the cave is located. Anyone with expertise in karst hydrology recognizes that inferences on groundwater flow routes in karst aquifers cannot be premised on surface topography. Remember, groundwater flows down-gradient; it can't look up and see whether or not it is passing beneath surface ridges, valleys, or other ownerships.

- ASA states that: "While it has been postulated that a major source of water for the Caverns is an aquifer within the Kartchner Block, several other studies (as cited by Graf) show that the primary source of water infiltrating the Caverns is rainfall." First, all aquifers receive their recharge from rainfall. More importantly, the sentence suggests that ASA does not wish to view the Kartchner Aquifer as an aquifer since it is highly dependent upon groundwater recharge by water that infiltrates from the surface and by water that sinks in the channels of washes. The Kartchner Aquifer is unquestionably an aquifer; it supplies known portions of the Caverns with a volume of over 100,000 gallons of water per year to off-set evaporation. Part of the definition of an aquifer is that it is useful; maintaining the beauty and natural integrity of Kartchner Caverns is clearly “useful”. The aquifer stores critical water between the infrequent precipitation events. At maximum water levels in the aquifer there is a million gallons of water pooled in known portions of the cave plus additional water stored in the sediments below the surface elevations of the cave floor.

- I do agree with ASA that the Kartchner Aquifer is highly dependent upon water infiltrating from the surface and upon water sinking in the channels of the washes. That is precisely the reason that the proposed resort threatens the park and the cave. The Kartchner Aquifer is very open to surface waters and susceptible to what occurs on the surface. Karst groundwater systems provide ineffective natural cleansing for waters that enter from the surface, and there is relatively little water within the aquifer to dilute introduced contaminants.

- ASA states that, unusual for most limestone caves, Kartchner has been subject to intrusion by hydrothermal solutions derived from the igneous and metamorphic surroundings. Based upon my search, none of the references cited in the ASA document indicate this mode of origin. Hill (1999) has discussed the origin and solutional development of Kartchner Caverns. She clearly states that hydrothermal activity occurred before the dissolving out of the cave. Such a glaring misstatement by ASA demonstrates that they did not take the time necessary to read and understand the existing technical studies done relative to Kartchner Caverns; the ASA review is superficial, inaccurate, and incomplete. Furthermore, ASA did not cite, and apparently did not use, most of the extensive pre-development studies conducted at Kartchner Caverns. Instead, they relied on a series of scientific articles published in the Journal of Cave and Karst Studies. These articles were only tangentially related to the practical land management and water quality and quantity protection issues that the proposed development raises with respect to the Park.

- ASA discusses thick deposits of quartz and illite bounding the caverns on the north. While the mapping by Thomson (1990) identifies a silicified zone north of much of the cave, the silicified zone thins and ends further to the west leaving a band of limestone about 1200 feet wide separating the silicified zone from the Saddle Wash Fault System. Furthermore, in a phone discussion with Dr. Thomson, he said that the silicified zone is highly fractured and that these fractures could readily transport water. In no way does the silicified zone protect water quality in the Kartchner Aquifer from proposed activities at the resort.

From the perspective of protecting Kartchner Caverns, there are two critical questions that must be considered in deciding whether or not to permit the proposed rezoning and development. First, is there a reasonable likelihood that significant portions of the area proposed for the resort lie within the recharge area for the Kartchner Aquifer? Second, is there a reasonable likelihood that the proposed resort development will adversely impact the park, the aquifer, and Kartchner Caverns? My answer to both questions is yes, it is more likely than not that significant portions of the resort contribute water to the Kartchner Aquifer and to Kartchner Caverns, and that the resort development will adversely impact the park and the caverns.

My answers to the questions are based upon investigations that others and I have conducted at the park, features and conditions discussed in this report, and my expertise in the delineation of recharge areas for important caves and karst springs. Over the last 30 years I have conducted well over 100 recharge area delineation studies in karst aquifers in a dozen states plus Canada and Australia; these have include both arid and humid areas. In contrast, ASA concludes that the geologic and hydrologic relationships, along with design and construction measures, will provide more than reasonable assurance that the proposed development will offer no adverse environmental or hydrologic impact to the developed Caverns. I have no knowledge of the extent of expertise that ASA has in karst hydrology and recharge area delineations. I suspect that the fundamental reason for the disparity of opinion is related to the extent of expertise in the unique characteristics of karst hydrology and in recharge area delineations and assessments.

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Biographical Sketch of Tom Aley

Tom Aley holds B.S. and M.S. degrees from the University of California at Berkeley. Beyond the M.S. degree he did additional graduate work focused on karst hydrology at Berkeley, at the University of Arizona (in the Department of Watershed Management), and at Southern Illinois University. Tom is certified by the American Institute of Hydrology as a Professional Hydrogeologist; is licensed in Missouri, Arkansas, and Kentucky as a Professional Geologist; and is registered by the Society of American Foresters as a Certified Forester.

Tom has 37 years of professional experience in groundwater hydrology with special emphasis on the impacts of land use and management on surface and groundwater resources in cave and karst regions. He designed and directed pre-development groundwater and cave microclimate investigations at Kartchner Caverns during the period 1989-1990. Tom has published over 70 scientific articles, and has taught approximately 40 professional short courses for the Association of Ground Water Scientists and Engineers, Environmental Education Enterprises, and the American Cave Conservation Association. Tom has consulted on cave and cave hydrology problems for the National Park Service at a number of parks including Mammoth Cave, Carlsbad Caverns, and Oregon Caves; for the United States Forest Service at Blanchard Springs Caverns, Arkansas and at numerous sites on the Tongass National Forest, Alaska; for a number of privately owned show caves in the United States; and for show cave operations in Canada, Barbados, Australia, and New Zealand.